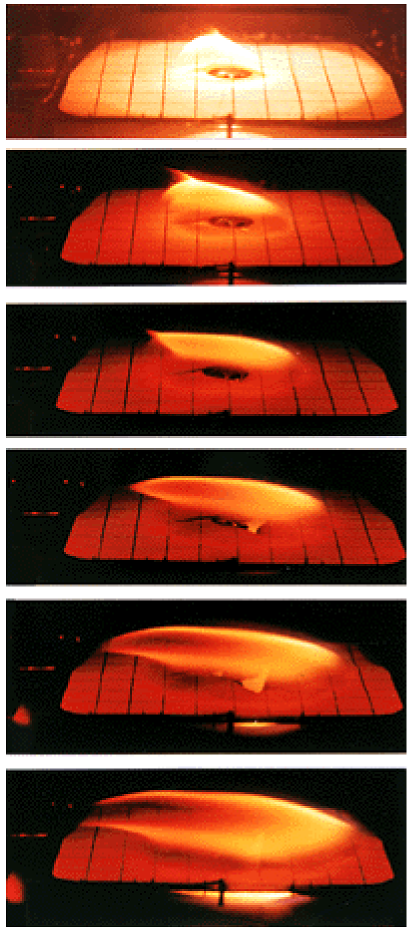
Shuttle Fire Tests Are Radiant



USMP-3 Radiative Ignition and Transition to Spread Investigation (RITSI) smoldering sample with flow entering from the right. Bifurcating smolder fronts are the glowing tips of each char peninsula.

Flame spreading is a phenomenon familiar to everyone who has witnessed an accidental fire. Yet, because of the complexity of the physical and chemical processes that are involved, the theoretical understanding of fires and flame spreading is a relatively new science. Flames spread along solid materials in a process where heat from the flames vaporizes the fuel just ahead of the moving flame. The vaporized fuel mixes with oxygen from the air and reacts chemically with it, producing the flame. On Earth, the spread rate of the flame is directly affected by the rate at which the fuel and oxygen are mixed with the help of buoyant convection.

Fires in spacecraft pose significant dangers to the crew. Toxic products can quickly poison the atmosphere and be difficult to remove, production of gases at high temperatures can lead to rapid overpressurization and rupture of the spacecraft, and extinguishing systems can damage critical electrical systems. This suggests that momentary ignitions due to electrical shorts or overheating might be an acceptable and recoverable hazard, but a transition from the ignition to fire growth is an unacceptable risk. To stop this transition, the conditions that allow transition must be avoided. Unfortunately, these conditions are not yet well known.

Flown on the USMP-3 mission, the Radiative Ignition and Transition to Spread Investigation (RITSI) studied the ignition process and the transition from this momentary ignition to a fire spread situation. Heating of the sample and ignition was via radiative heat transfer and absorption with a subsequent transition to flame spread in low gravity in the presence of very low-speed airflows in two-dimensional (2D) and three-dimensional (3D) configurations. In the 2D tests, ignition occurred across the full width of the fuel sample to initiate planar 2D spread in the axial direction. In the 3D tests, ignition was isolated to a central spot, allowing spread to occur in all dimensions. The key aspect of this approach is that a flame may spread simultaneously both upstream and downstream, or it may split into two or more flames that propagate at different rates and extinguish at different times. The airstream, however, comes principally from one direction, at magnitudes from 1 to 15 cm/sec. This arrangement is both more realistic as a fire scenario in space and is also unachievable at these flow speeds on Earth.

RITSI hardware consists of a flow duct with screens at both ends and a fan that pulls air through the duct. Some samples are rectangular to allow for 2D flame spread, and some are square to allow for 3D flame spread. A radiant heater, and when needed, a hot wire, are used to ignite the samples. Some samples were doped with a smoldering promoter to study smoldering rather than flaming combustion. Six thermocouples and an ignitor wire were preinstalled on each sample holder. The thermocouple data were recorded along with radiant heater power, ignitor power, and flow velocity.

A total of 25 tests conducted with ashless filter paper produced many exciting surprises. The first surprise was that radiative ignition by the lamp followed by successful transition to flame spread occurred in all experiments except at zero external velocity. This has never been observed at normal gravity; that is, ignition in 1g always needed the assistance of a hot wire ignitor near the fuel surface. This finding indicates that the transition tends to be easier in microgravity than in normal gravity. Another interesting observation was that the flame did not spread downstream at all in air (along the direction of the external flow) following ignition at the middle part of a sample. The flame spread upstream, however, in the shape of a fan; the spread rate was most rapid directly in the direction of the incoming flow and gradually slowed down to zero in the direction normal to the incoming flow. With an increase in the incoming air flow velocity, the fan angle increased due to an increase in oxygen supply rate. These two trends are completely opposite to those observed in normal gravity, where spread is much more rapid downstream and the fan angle narrows with an increase in the incoming flow velocity.

Three narrow samples (4-cm-wide instead of the regular 10-cm-wide sample) with two open sides were used to examine flame spread characteristics along the open edges. The results show that once a flame reaches the edge of the sample, it spreads much faster than it does along the center of the sample. With 2 cm/sec external air speed, a flame only spreads upstream along the edges; but at forced air speeds greater than 3.5 cm/sec flow, a flame spreads both upstream and downstream along the sample edges. At the downstream edge, the flame spread rate appears to be the highest. RITSI also studied the effects of a corner on flame spread, using a 90° bend at one side of the sample. Slowdown of the approaching flame toward the corner was observed, but a flame coming from the open corner side (270°) appeared and spread rapidly along the open corner. These results show that there are significant effects of the 3D geometrical configuration on flame spread which cannot be observed by a 2D configuration. Since the flame spreads much faster than it does in the 2D configuration, these 3D flame spread configurations would be more relevant to fire safety in microgravity.

The development of a model and associated numerical codes are nearing completion, and experimental data are being compared with predicted results. From the comparison, the validity of our understanding of ignition and flame spread mechanisms can be assessed and any deficiencies pointed out.

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